



# Alignment of critical and noncritical machines

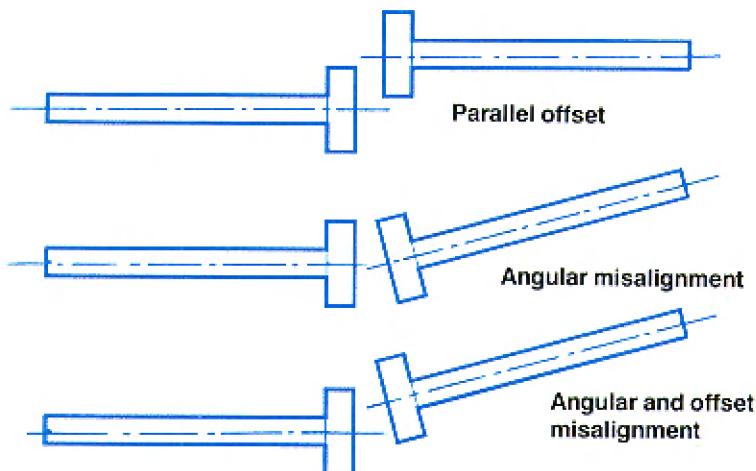


Figure 1:  
Types of misalignment

by Stanley R. Bognatz, P.E.  
Machinery Diagnostic Services  
Bently Nevada Corporation

**M**isalignment is estimated to cause over 70% of rotating machinery vibration problems. Without proper alignment, rotating machinery may experience increased vibration and, more importantly, higher stress levels. Machinery users readily realize the value of proper alignment on critical, non-spared machinery, such as turbine-generators, boiler feed pumps and large compressors. Considerable time and money are usually spent aligning such machine trains. However, less emphasis is often placed on smaller, less critical equipment. This is unfortunate because, regardless of size, misaligned machines experience reduced operating efficiency, increased coupling and shaft stresses, decreased component life and reduced overall reliability. To help understand alignment procedures in general, a brief overview of alignment is necessary.

### What is alignment?

Alignment is the act of positioning machine shafts to have their axes collinear, or form a straight line, when the machine is running under normal load. It can sometimes be a relatively easy task, as in the case of a small motor-pump unit. The procedure becomes more complex when more than two machines are coupled, such as large turbine-generator trains or units with gearboxes between the driver and driven machinery.

Positioning the shafts generally requires moving the bearing housings. On some machines, the bearing housings are directly attached to the machine casing. Therefore, to move the shaft, the entire machine must be moved. This is easier than it sounds. If the bearing housings are attached directly to the casing, no internal clearances (oil and dust seals, air gaps, etc.) are modified during realignment. On other machines, the bearing housings and casing are mounted separately. Once the bearing housings are positioned for proper shaft-to-shaft alignment, internal clear-

ances must be checked and, if unacceptable, the machine casing(s) must be moved accordingly.

### What is misalignment?

Misalignment occurs when the axes of adjacent shafts are not collinear when operating under normal load. There are three general types of misalignment: parallel offset, angular, and combined angular and offset. These are shown in Figure 1.

Parallel offset misalignment occurs when the shafts are parallel to each other, but offset by some amount. Angular offset misalignment occurs when the shaft centerlines intersect at an angle at the coupling. These two types of misalignment are not usually present by themselves, but are found combined in varying degrees.

Misalignment introduces forces at the coupling that should not otherwise be present. These forces create additional alternating stresses on the coupling and shafts. Given high enough stresses, and sufficient operating time, the endurance limit of the materials may be exceeded, and the shaft or coupling may fail.

### What is acceptable misalignment?

Misaligned shafts generate reaction forces in the coupling, which affect the machines and are often a major cause of vibration. The effect that misalignment has on the machines is a function of the compliance of the coupling. All torsionally loaded (i.e., operating under load), misaligned couplings have restoring moments, which tend to bow the machine shafts, causing 1X vibration. The bow is greater on higher speed shafts that carry higher torques for a given size machine [Ref. 1]. Therefore, it is common practice among coupling Original Equipment Manufacturers (OEM) to specify a misalignment tolerance for a particular coupling. This tolerance keeps reaction forces within the limits of the coupling materials and minimizes misalignment-induced vibration. The tolerance is usually specified in mils of misalignment per inch of coupling distance (mils/inch), or in degrees of allowable angular misalignment.

Coupling alignment measurements allow us to calculate the offsets of each shaft centerline relative to the other, across the coupling distance, in the horizontal and vertical directions. This gives us a measure of misalignment. We plot this measurement on a graph developed by John Piotrowski. John Piotrowski's graph specifies alignment accuracy as a function of the vertical and horizontal offsets, at each side of the coupling, versus speed. From this graph, we determine if realignment is required. We prefer to use John Piotrowski's graph even if OEM data is available, because its more rigorous alignment standard minimizes shaft strain.

### How do we measure misalignment?

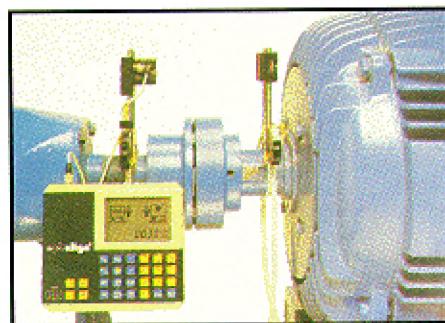
Misalignment is measured across the coupling between two shafts. The data shows the spatial relationship of one shaft to another. Bently Nevada's Machinery Diagnostic Services (MDS) group uses several different methods, depending on the machines being aligned.

- Laser Alignment Units:** These units consist of a laser mounted on an adapter. The adapter is fixed to the shaft on one side of the coupling, behind the hub. A second laser, or a prism, is affixed to the shaft on the opposite side of the coupling. The laser and prism are connected to a dedicated computer. As the shaft is rotated, the computer records the alignment readings at multiple positions, typically every 90°. The process is usually repeated two or three times to ensure accurate results. Given machine dimensions, the computer will calculate the amount of misalignment at the coupling and the corrections necessary at each machine foot to achieve a correct static, or cold alignment. (It's a cold alignment because the machine is not running.) MDS prefers these systems as they are efficient and very accurate.

- Reverse Dial Indicator Alignment:** A bracket, which has an extension arm with a dial indicator mounted on its end, is fixed to one shaft. The indicator is mounted to read on the outside diameter of the opposite coupling



Steam turbine and compressor coupling alignment



Optalign laser system

hub. The indicator is mounted at top-dead-center on the hub and calibrated to read zero. Readings are taken every 90° as the shafts are rotated. If two brackets are used, readings can be taken from both shafts simultaneously. These readings are reduced and plotted on graph paper. Alignment corrections are measured directly from the graph. This is probably the most accurate of the dial indicator-based methods. This method is used when laser systems are unavailable or unsuitable for the machine.

- Rim and Face:** A bracket-mounted dial indicator is used to take readings from the outside diameter (rim) of the opposite coupling hub while one shaft is rotated. Readings are then taken axially on the inside face of the coupling. The data is reduced, plotted and corrections calculated. This method is subject to several sources of error and is generally not as accurate as the laser and reverse dial indicator methods, though in some situations it is necessary to use this method.

- Optical Alignment:** Optical alignment equipment generally consists of a precision jig transit or sight level accu-

rate to 1 arc-second (25.4 μm over 5.2 meters, or 0.001 inch over 17 feet), a portable instrument stand, measurement scales, and tooling for mounting the scales on machines. This method is very accurate and especially useful on long machine trains. It directly shows us the alignment of each rotor in the machine train, and the catenary shape of the entire shaft system. This is done by placing scales directly on the shaft and obtaining readings from the scales.

### What is Optical Alignment used for?

Optical Alignment is used on machines that have rigid couplings or are not easily measured using the Laser, Reverse Dial Indicator or Rim and Face alignment methods. Examples are large turbine-generator trains and hydro-turbines. On these machines, Optical Alignment equipment directly measures the shaft's position at each bearing. This equipment is very versatile. We use it primarily for:

- Thermal growth and movement studies of machines:** To acquire thermal growth data on a machine, we first permanently install dowel pins just below the split line on each side of each bearing housing. We also install benchmarks off the machine to provide reference points for the transit; all measurements are relative to the benchmarks.

After the machine is set up, readings are taken with the machine running at base load - this is our dynamic or hot data. Scales are mounted on the dowel pins and readings taken in the horizontal and vertical directions. After the machine has been shut down and allowed to cool for 24 to 48 hours (48 hours or more is preferred on larger units), a second set of readings are obtained - the static or cold data. By calculating the differences between the dynamic and static data, we have an accurate measure of the thermal growth at each bearing housing. The hot-cold sequence is typical of pre-outage work and can be reversed to a cold-hot sequence for startups.

By plotting the thermal growth data in conjunction with coupling alignment

data, we can determine how much the machine should be moved while at rest, so that, when operating under full load, the alignment is acceptable. Keep in mind that, unless a machine has zero thermal growth, setting a "perfect" cold coupling alignment will yield a misaligned hot machine. It is essential that we misalign the cold machine in order for it to "grow" into a well-aligned position.

Some plants routinely perform their own alignment on critical machines using thermal growth data provided by the OEM. If this data is calculated (not measured) it will generally not be as accurate as the results of a thermal growth study. This can severely compromise the outcome of an alignment project. MDS can assist customers by performing thermal growth studies, which will make their alignment more accurate.

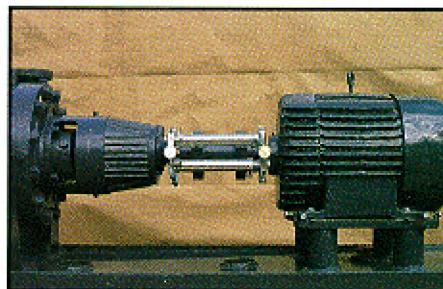
- **Internal alignment of rotating and reciprocating machinery:** During major outages, it is common to dismantle machines to varying degrees. Seals, shafts and other components are removed to accomplish the outage objectives. When the machine is reassembled, it is essential to properly set the internal alignment of diaphragms, seals and bearings to avoid rubs during startup. We use optical equipment to level baseplates, set catenary positions, set seal and diaphragm positions, and determine the alignment of machinery.

On reciprocating machinery, the alignment of the bed-section and cylinder bores, crank and bearings is critical to proper performance. Optical equipment allows us to efficiently and accurately align these components for reliable operation.

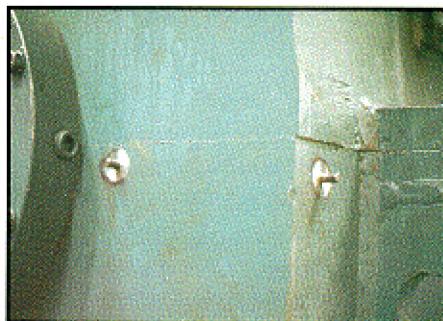
### How do we correct misalignment?

Besides internal alignment work, there are two general types of alignment work we assist our customers with. One requires only coupling alignment data; the other both coupling alignment and thermal growth (optical) data.

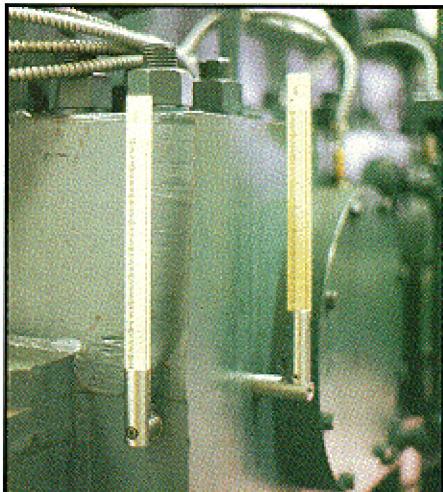
Typically, only coupling alignment is required for machinery where thermal growth is not expected to be significant.



Reverse Dial Indicator Alignment



Dowel pin referenced points



Optical scales on reference points

Usually, the alignment can be accomplished in a few hours using either Laser or Reverse Dial Indicator equipment. Projects that require both coupling alignment and thermal growth data are generally our customers' larger, more critical machinery. Gas and steam turbine-generators, turbine-compressor trains and boiler feed pumps are prime examples. A typical "pre-outage" job might proceed as follows:

- Set up the machine train with dowel pins and benchmarks for obtaining optical data. This can be done any time prior to the outage.
- Obtain hot optical data at base load before the unit is shut down. This

can also be done any time prior to the outage.

- After the unit is shut down and allowed to cool for 24 to 48 hours, obtain cold optical data.
- Obtain coupling alignment data using the Laser or Reverse Dial Indicator setups.
- Reduce the optical and coupling alignment data, plot it, and determine how much each machine must be moved to achieve an accurate hot alignment.
- Perform the appropriate shim changes on each machine foot to achieve the desired alignment.
- If time permits, take another set of coupling alignment readings to verify the machine is positioned as desired. Readjust shims if necessary.

If the plant were coming out of an outage, we would reverse this procedure. We would set dowel pins and benchmarks and take coupling and cold optical data during the outage. After startup and a day or two of base load operation, we would take the hot optical data. Then we would reduce and plot the data and determine if any additional correction to the alignment was required. If so, the shim changes would be implemented during the next shutdown.

### Conclusion

With accurate alignment, any machine, critical or not, will provide better service and greater efficiency and reliability. Bently Nevada's Machinery Diagnostic Services group has alignment experience with almost every class of rotating and reciprocating machinery. We also have the equipment and expertise to help you align smaller machines quickly, efficiently and cost-effectively. Contact your nearest Bently Nevada sales and service representative for more information. ■

### References

1. Gibbons, C.B., "Coupling Misalignment Forces," Proceedings of the Fifth Turbomachinery Symposium.
2. Campbell, Alastair J., "Static and dynamic alignment of turbomachinery," Orbit, Volume 14, No. 2, June, 1993.
3. Campbell, Alastair J., "Alignment of reciprocating compressors," Orbit, Volume 12, No. 1, February 1991.